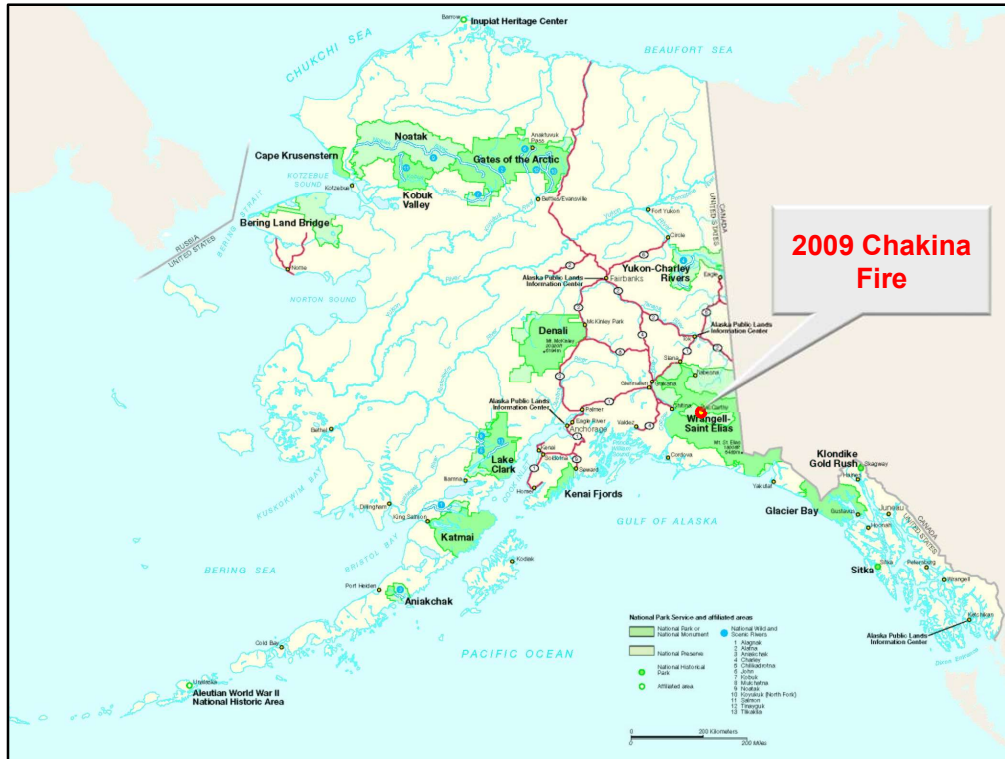


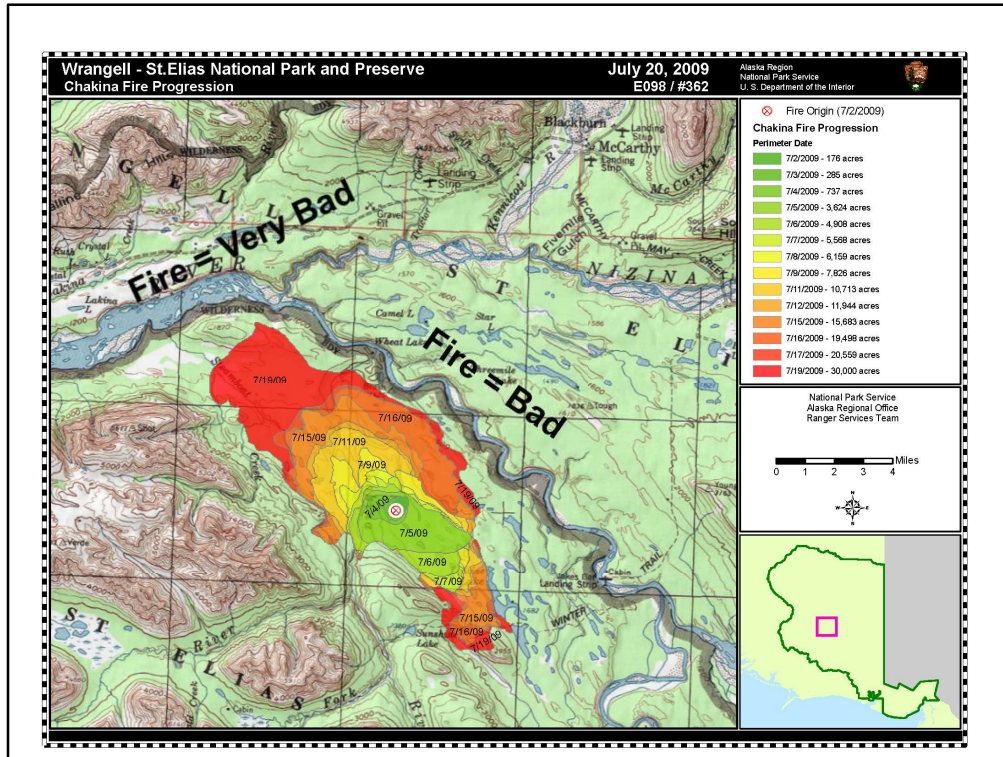
# The Chakina Fire and the Spotting Problem

A case study in using geospatial  
and non-geospatial fire behavior  
models to assess spotting potential

Brian Sorbel, National Park Service  
Tonja Opperman, Wildland Fire Management RD&A – USFS  
Pat Stephen, NPS/USFS (retired)



We're going to talk today about a fire that Tonja and I both did some analysis work on during the summer of 2009. That fire is the Chikina fire which occurred in Alaska's Wrangell-St. Elias National Park and Preserve, shown here on this map.



The Chakina fire was caused by lightning and started in early July 2009 (the start of an extreme Alaska fire season). The fire started in an area designated to receive Limited fire protection, sort of like a WFU area.

However, from day one, it was always recognized that there was some potential for the fire to move towards and then spot over the Chitina River into an area designated for Full fire protection within the Alaska Interagency Fire Management Plan. So, from an analysis perspective, the main issue wasn't as much modeling fire growth, as is often the case, as it was modeling the potential for spotting over the Chitina river.



Here we can see the Chitina river with the Chakina fire off in the distance. There are continuous fuels between the fire and the river, and then continuous fuels across the river, roughly 200 meters wide in the area shown here.

## Management Questions and Modeling Options

- What is the likelihood of the Chakina fire spotting across the Chitina river?

- What type of winds (speed and direction) are required to produce spotting?
- What is the probability of spotting at different wind speeds?
- Where is spotting most likely to occur?

- Modeling Options

- No Modeling
- Non-Spatial modeling (Behave Plus)
- Geospatial modeling (FARSITE, STFB, FSPro, etc.)

What does it take to breach the barrier?

What is the minimum windspeed and direction that could produce spotting across the 200 – 400 meter wide river?

It's not like they were going to hang their hats on the modeling outputs, but they wanted us to characterize the conditions for which they should be prepared, if those conditions appeared in the weather forecast or otherwise materialized.

If spotting occurs, what happens next?

Question has several parts:

Can an ember travel the distance of the river's width?

- what species is lofting embers

- how many trees are torching at once

- what is the topography from ember to landing zone

If yes, will it ignite?

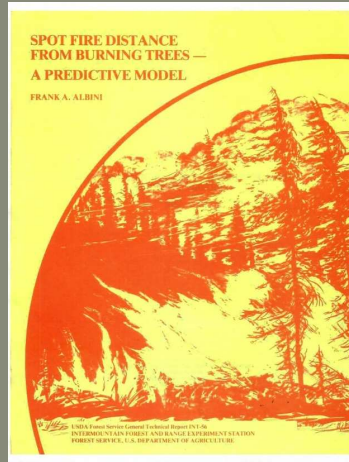
- what time of day might the fire reach the lofting-embers stage?



Again, 2009 was an extreme Alaska fire season. Fuels in the area were black spruce and white spruce, primed to burn and receptive to embers from torching trees. Obviously no shortage of torching fuels, ember lofting...

# Spot Fire Distance From Burning Trees – A Predictive Model (Albini 1979)

- “This vexing phenomenon...”
- The paper “presents a theoretical framework ... for predicting the maximum spot fire distance from burning trees.”
- “The problem addressed in this paper arises under conditions of intermediate fire severity.”



Regardless of what model is used, when it comes to spotting, they all have their roots in Albini 1979.

“Situations not considered in this work are those extreme cases in which spotting may occur up to tens of miles from the main front, as in running crown fires.”

## Addressing the problem using non-geospatial fire behavior models (BehavePlus)

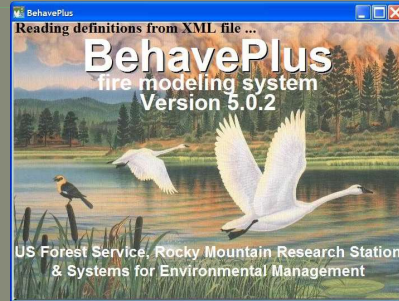
- Approach: Visually identify areas along the river where spotting seemed most likely to occur.
- Use BehavePlus to determine the wind speed required to produce spotting at those locations.

# BehavePlus: Spotting Distance (SPOT')

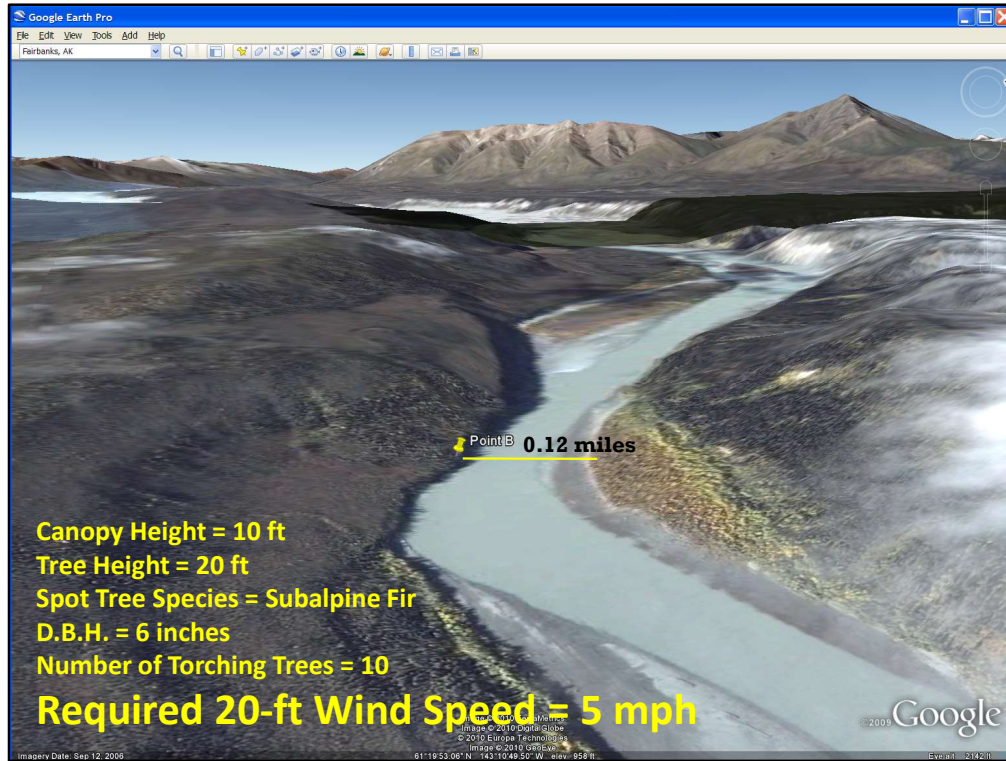
- Inputs

- Downwind Canopy Height
- Torching Tree Height
- Spotting Tree Species
- D.B.H. of Spotting tree(s)
- 20-ft Wind Speed
- Number of Torching Trees
- Ridge-to Valley Elevation Difference
- Ridge to Valley Horizontal Distance
- Spotting Source Location

- Output: Maximum Spot Fire Distance From Torching Trees

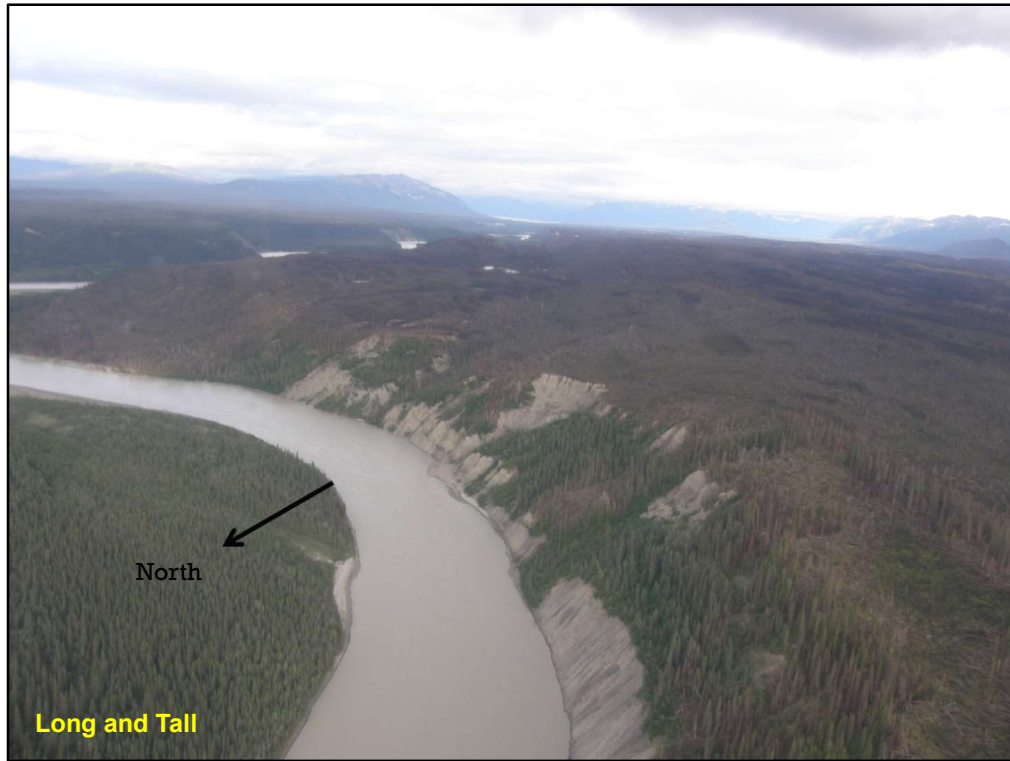


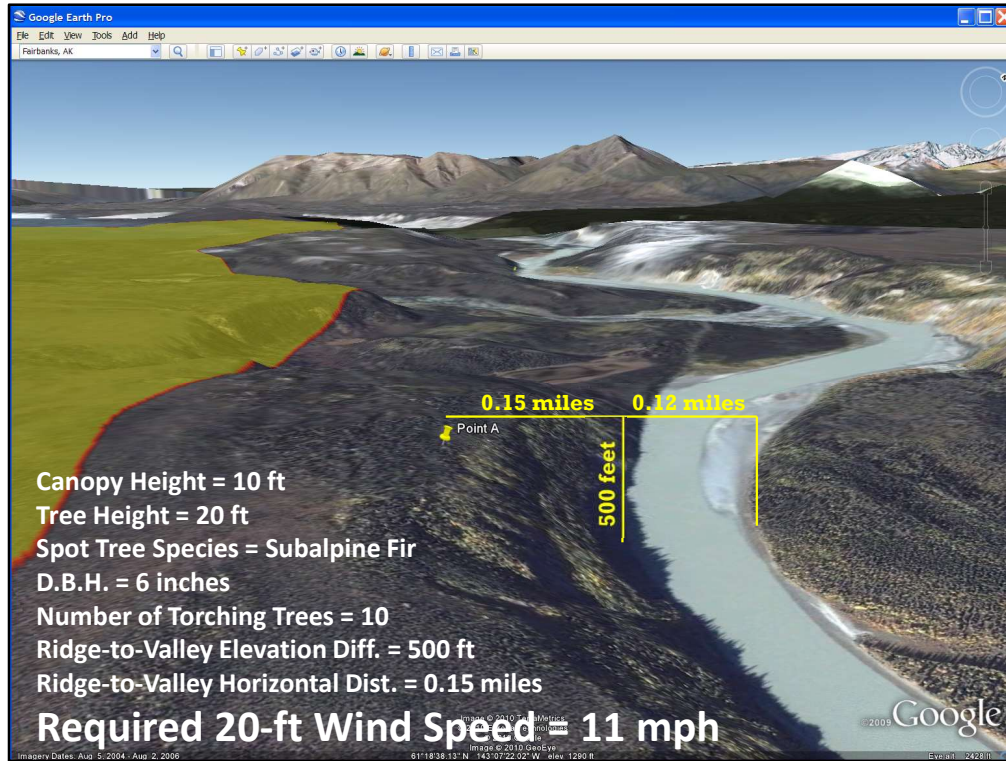




The inputs were based on where we thought spotting was most likely—the shortest distance across the river.

This is showing results on flat terrain, correct?





...and this is showing inputs for spotting potential from the ridgetop, at the same location as the previous scenario. Note, the required wind speed is the same, with or without the terrain inputs. As far as BehavePlus is concerned, a 500 ft bluff doesn't matter.

*Why do we use only one torching tree? We could mention in the geospatial sections that we don't really know the "number of torching trees" that is used in the modeling....it is calculated in the background and sort of hidden.*

# BehavePlus: Probability of Ignition from a Firebrand

Spotting Threat by Distance of Embers (mi) and Probability of Ignition (%) based on FFMC and Windspeed

Windspeed (mph)	Fine Fuel Moisture Code (Temps from 50-80F)				
	>90	86-89	82-85	76-84	70-75
30 mph	0.8 mi 67-74%	0.8 mi 50-56%	0.8 mi 37-42%	0.8 mi 27-32%	0.8 mi 20-23%
25 mph	0.7 mi 67-74%	0.7 mi 50-56%	0.7 mi 37-42%	0.7 mi 27-32%	0.7 mi 20-23%
20 mph	0.5 mi 67-74%	0.5 mi 50-56%	0.5 mi 37-42%	0.5 mi 27-32%	0.5 mi 20-23%
15 mph	0.4 mi 67-74%	0.4 mi 50-56%	0.4 mi 37-42%	0.4 mi 27-32%	0.4 mi 20-23%
10 mph	0.25 mi 67-74%	0.25 mi 50-56%	0.25 mi 37-42%	0.25 mi 27-32%	0.25 mi 20-23%

After all that tabulating in B+, we developed a matrix for the IC....

Maximum spotting distance is shown for each windspeed from 10-30mph.

The probability of a firebrand igniting a fire was added for various levels of dryness, as indicated by the FFMCcode, 70-90+

The result was a combination of risk of breach and risk of ignition, with the colors representing somewhat arbitrary levels of low, moderate, and high risk.

Not geospatial, but shows variation in maximum distances with various wind speeds as a “pocket card” for reference for various situations.

*Might note that there is no “probability of ignition” considered in any of the geospatial models—you can only get it from B+ or fireline handbook.*

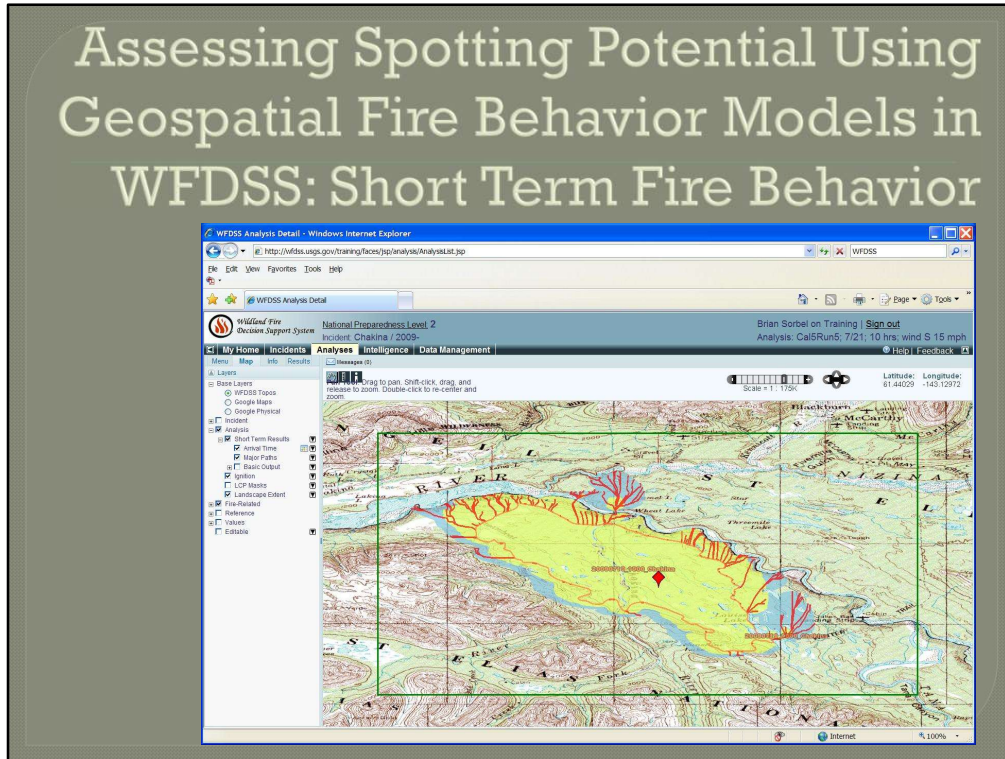
## Answering the Question with Behave Plus

- Windspeeds between 5 – 10 mph appear to be sufficient to produce spotting across the narrower portions of the river.
- Terrain effects are virtually ignored at the scale of the 500 ft bluffs; no advantage is given to the bluff area in terms of a greater spotting distance.
- The SPOT module gives the max ember distance, but not the probability of a spot fire occurring.
- Probability of Ignition can be used in conjunction with the Maximum Spotting Distance to gauge the likelihood of spot fire growth.

Results tell us that a 5-10 mph wind can result in spotting distances greater than the barrier width.

But it doesn't implicitly tell us whether ember lofting is likely from the narrowest points along the river—we have to assume torching occurs here, or run that fire behavior separately.

# Assessing Spotting Potential Using Geospatial Fire Behavior Models in WFDSS: Short Term Fire Behavior

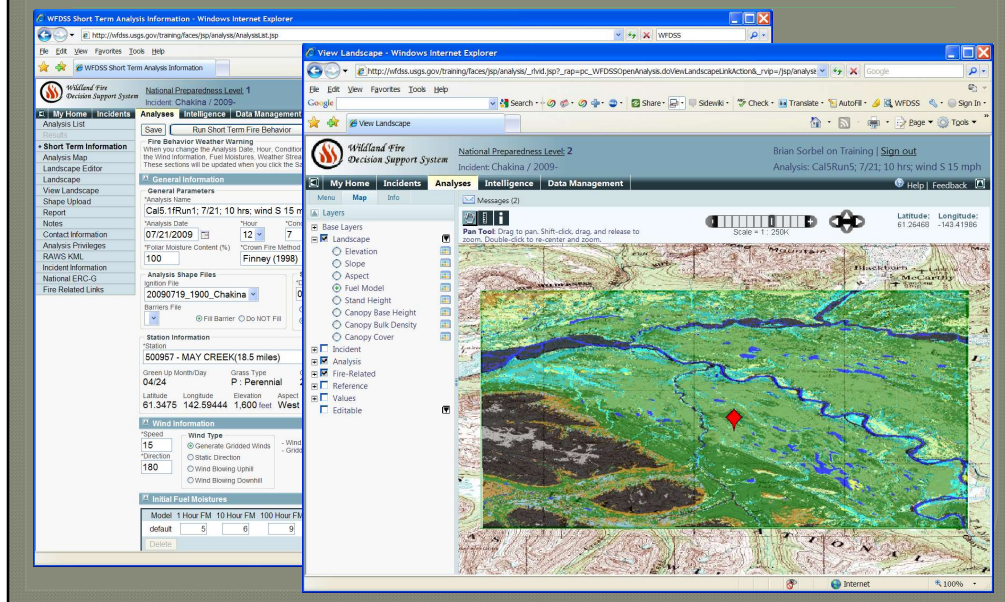


We had results from B+, but we realized that we could run B+ in a lot of different ways in order to capture the variation in the landscape topography, fuels, and fire behavior conditions. We also weren't getting at the probability that embers were going to be lofted in terms of crown fire potential. Although crown fire potential can be determined using B+, it is not spatially displayed. We were getting the max distance from B+ but not getting at the likelihood for it to occur at a specific location.

We knew FlamMap could spatially display potential for torching (and therefore ember lofting), but desktop FlamMap doesn't include the spotting module.

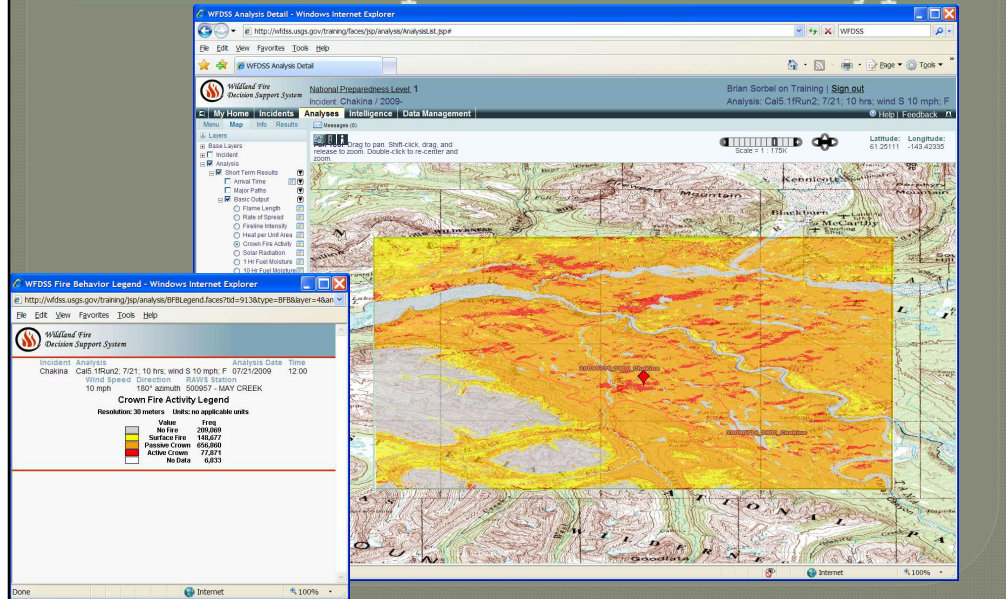
Therefore, we looked at STFB.....

# Short Term Fire Behavior Inputs



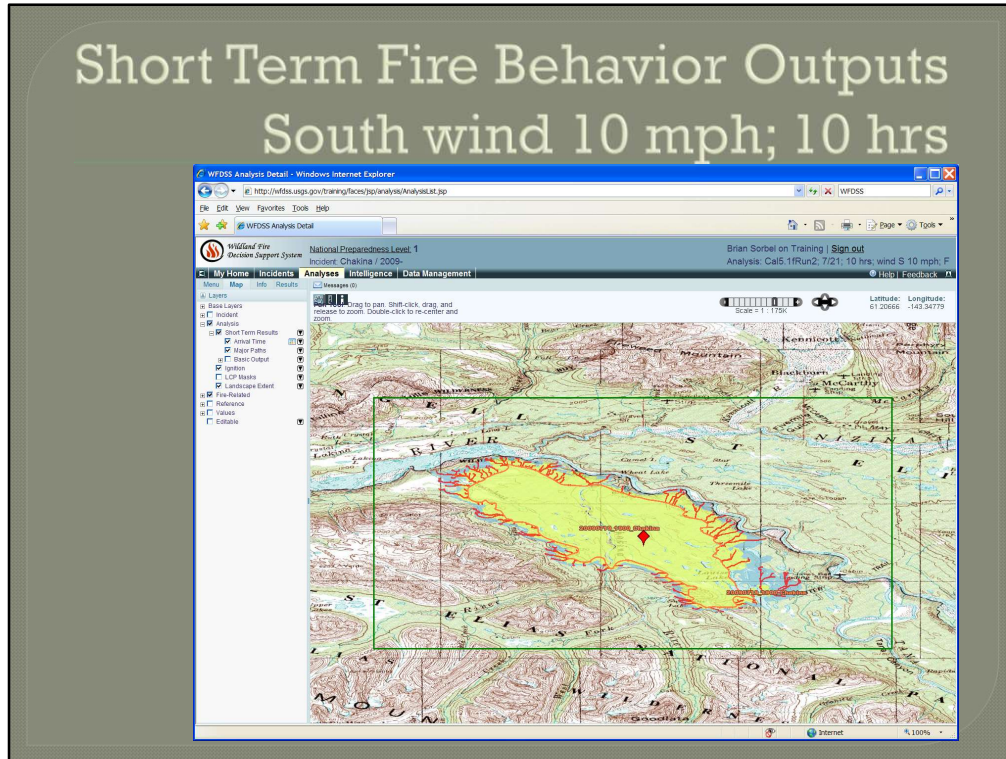
# Short Term Fire Behavior Outputs

## Basic Output: Crown Fire Type



# Short Term Fire Behavior Outputs

## South wind 10 mph; 10 hrs



Show how STFB can indicate where torching will occur on the LCP, as well as spot fires, under these different scenarios.

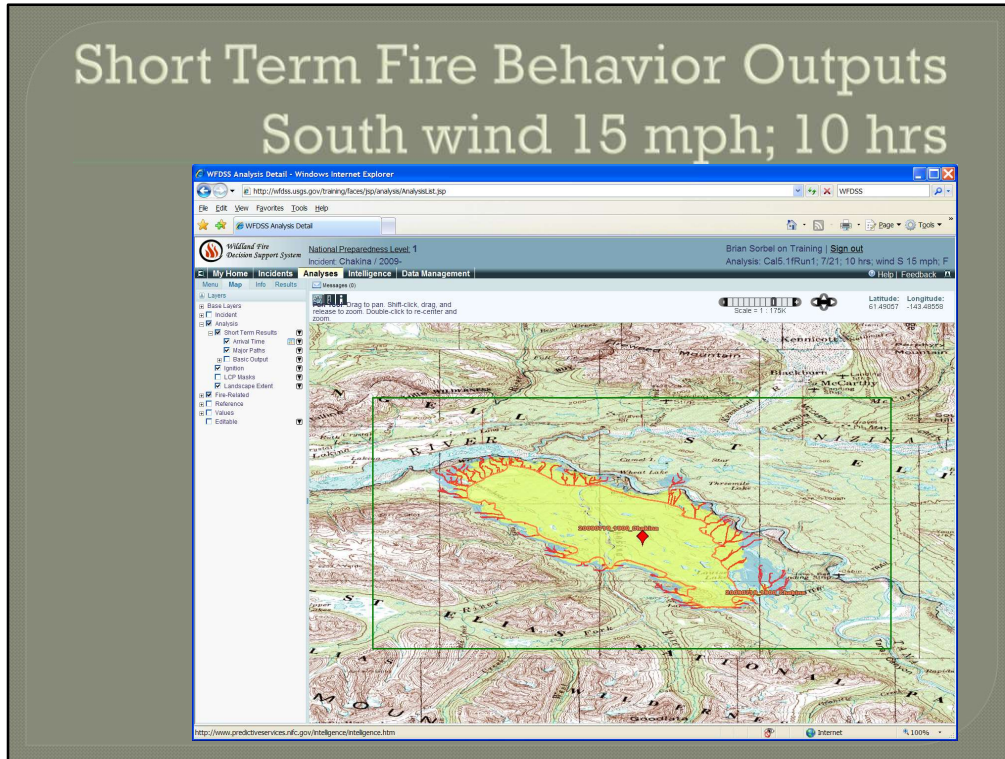
Here is 10mph South winds....

You can get grids of fire behavior without having to “grow” the fire to that location as you do in FARSITE.

*Is this showing mostly surface fire behavior?*

# Short Term Fire Behavior Outputs

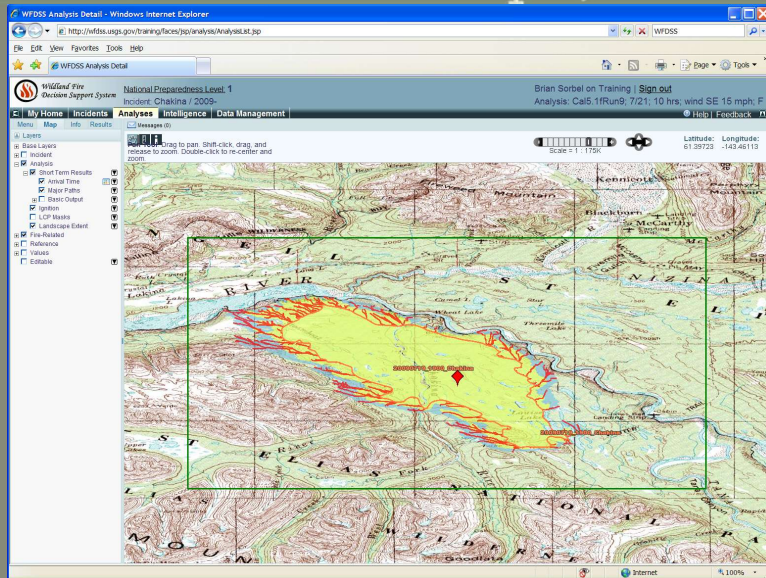
## South wind 15 mph; 10 hrs



....and here is 15 mph South winds.

# Short Term Fire Behavior Outputs

## Southeast wind 15 mph; 10 hrs



And you can easily assess other wind directions....here is 15 mph SE winds.

## Answering the Question with Short Term Fire Behavior

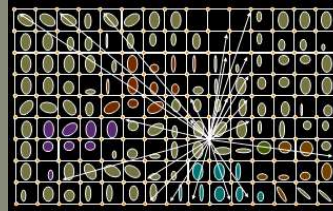
- Minimum required wind speed (in 5 mph increments) required to produce spotting across the Chitina River
  - Southwest – 10 mph
  - South – 15 mph
  - West – 20 mph
  - Southeast – 25 mph
- Problems: Every STFB run is different because spotting is stochastic, and no way to tell if max ember distance was used.

Although every run is different in terms of spotting, we can *visualize* where torching is likely under different wind scenarios by looking at the fire behavior grids.

*Maybe turn the results portion into a graphic/map?*  
*Fire behavior is not stochastic.*

## Spotting Process in Short Term Fire Behavior (In Brief)

- For every cell on the landscape where torching is predicted to occur, 16 “test” embers are lofted and only the maximum ember distance and angle of travel is recorded.
- During MTT, the user-defined Spotting Probability is used to randomly determine which torching cells produce a single ember.
- Embers are produced from a fixed grid—limited opportunities to loft an ember.



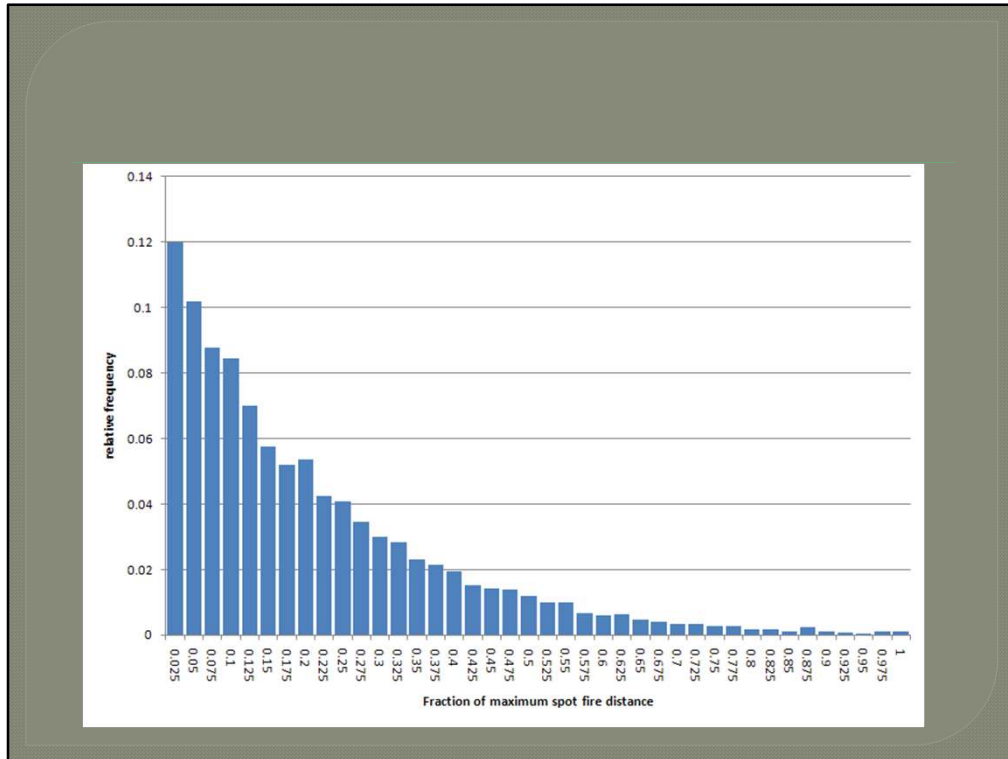
“Fixed Grid – Single Ember”

*Reference the handout for practitioners...*

*Some sort of a graphic could make this much clearer.....could we add a square grid showing “nodes”?*

*Brian, note that I added 16 to bullet #1 and added “a single ember” to bullet #2.*

*I moved your bullet 3 to the next slide and added a different bullet #3.*



Describe how embers are thrown out, negative exponential distribution

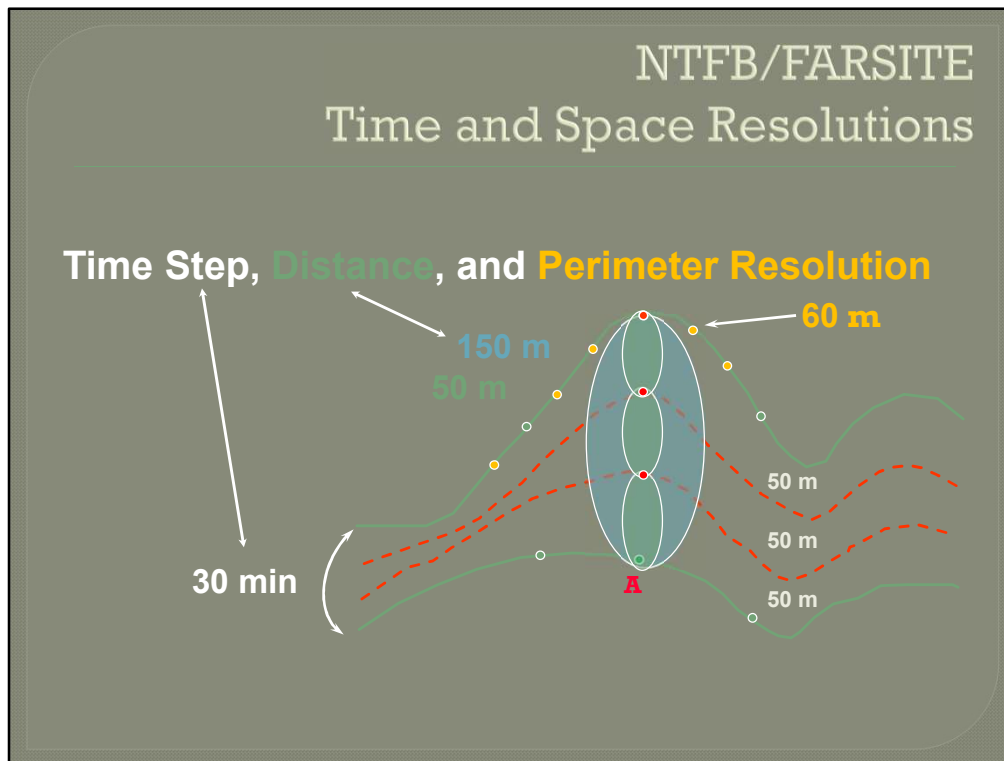
## Answering the Question with NTFB/FARSITE

- Inputs:
  - Canopy characteristics from spatial layers
  - Foliar moisture set by user
  - Tree species/dbh set by user (FARSITE); Grand Fir at 20cm constant in NTFB.
  - “Spotting percent” set by user
  - Weather (min/max) input by user for each day
  - Wind can vary at any temporal scale throughout burn periods; can be gridded
- Output: geospatial fire growth and behavior over time and space

We thought about using FARSITE...which is now incorporated into WFDSS as “Near Term Fire Behavior” (It wasn’t during the 2009 Chakina Fire).

It is geospatial, show mapped outputs of fire behavior, & has both crown fire methods. The inputs are listed on the slide.

The output is geospatial fire growth and behavior...so the power of FARSITE is that it can be used to “grow” fires in hourly or daily periods. And this means that it can often require quite a bit of set-up, data acquisition, and calibration.



“copy” of the slide before I messed with it....

In NTFB & FARSITE, the new fire perimeter is projected using ellipses that start and end at “vertices”.

If the Distance Resolution is set to 150 meters, represented by the blue ellipses from points A & B, embers are only lofted from 4 vertices, 2 at the beginning and 2 at the end.

However, if the Distance Resolution is reduced to 50 meters (see the aqua and pink ellipses), there are several sub-timesteps represented by red dashed lines, several more ellipses, and several more vertices.

With the Perimeter Resolution set to 60 meters in this example, the addition of a new set of ellipses (shown in green), also increases the number of vertices.

Again, each vertex lofts 16 embers that are reduced in number by the user-set spotting probability before they are “flown”.

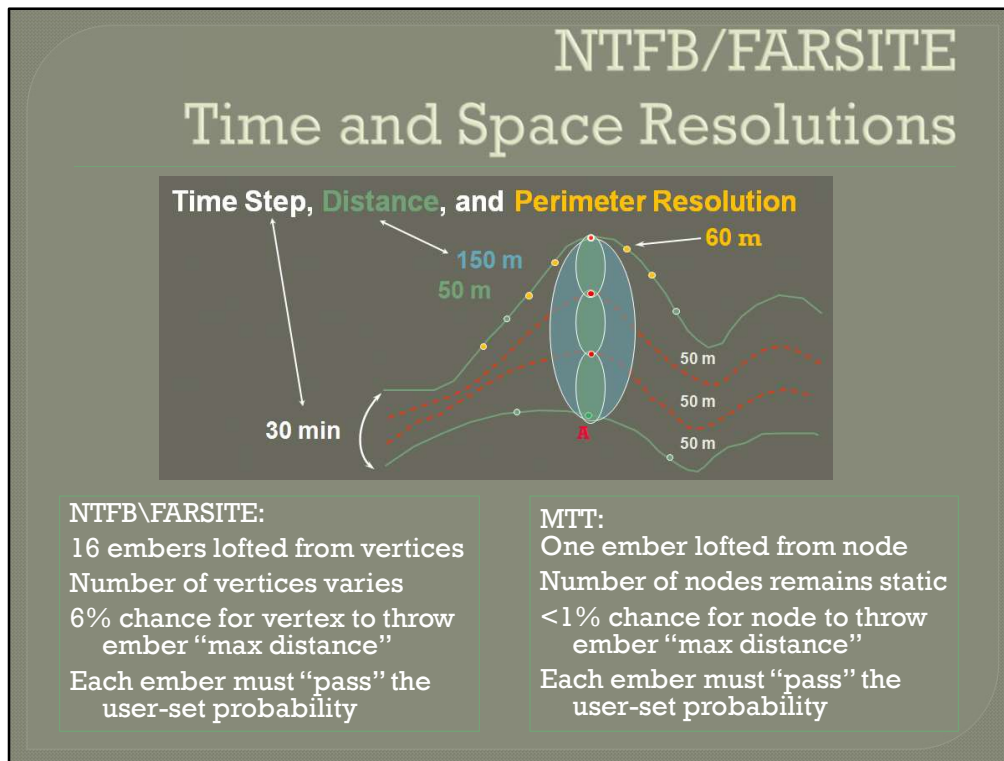
Without a lot of experience, users have little control over the number of opportunities for embers to be lofted. This slide is not meant to explain all the nuances of spotting in FARSITE, but to illustrate that it is more complex than what is occurring in a square grid with Minimum Travel Time methods.

The moral of the story is that a much lower spotting probability is needed in NTFB/FARSITE than MTT-based models.

The level of spotting is based on these inputs, and the more finely they are set, the more spotting will occur.

Vertices have 16 chances to beat the user-set “extinguishment rate”, but in MTT there is only one ember.

FARSITE has a 1/16<sup>th</sup> chance of choosing the farthest ember, but MTT has a very very small chance to choosing the farthest ember.



It is important to note that FARSITE has a different way of implementing ember production than the tools that use MTT.

In NTFB & FARSITE, the new fire perimeter is projected using ellipses that start and end at "vertices", not fixed "nodes".

Users have little control over the number of vertices.

This slide illustrates some of that complexity:

With the large blue ellipse where Distance Resolution is 150 meters, with Time Step 30) you get one vertex at the top of the blue ellipse.

But if Distance Resolution is 50 meters with Time Step 30, you get 3 vertices before the next expansion wave is drawn.

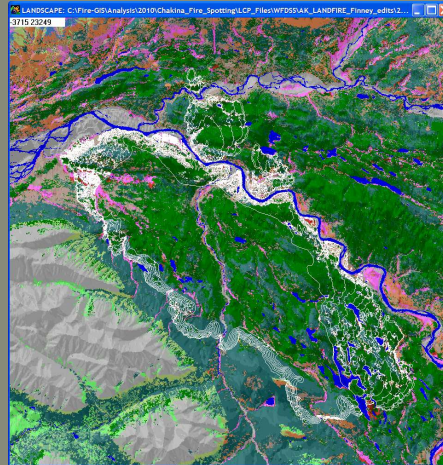
Additionally, the Perimeter resolution is adding/subtracting vertices to maintain spacing along the new perimeter.

The bottom of the slide shows a few of the comparisons between the two spot distance methods.....

The moral of the story is that a much lower spotting probability is needed in NTFB/FARSITE than MTT-based models when trying to simulate fire GROWTH.

## Answering the Question with NTFB/FARSITE

- “Real” wind stream does not capture thresholds.
- Used same CF method (Finney).
- Used constant wind speed/direction.
- Spotting was 2.5%.
- Fire crossed river at 15mph.



So, we didn't use FARSITE back in 2009, but we did run it for the sake of comparison in this presentation.

We didn't want to use a “real” wind stream with variable winds because then we wouldn't know if the winds of concern occurred at the point necessary to loft embers across the river, and we were looking for “potential” or “worst case” under a specific wind scenario, not trying to model actual growth.

We used the same Crown Fire method (Finney) that was used in STFB.

We made the weather and wind the same every day and all other applicable settings the same.

FARSITE spotting is set relatively low at 2.5% due to computational limits, but this is a “normal” value.

The results show..... That spotting was modeled with South winds of 15mph.

But this is not the best tool for our question b/c of the time/space issue. We are looking for the breaching of a specific barrier.

We have to make the fire get to the barrier edge at the right time, which would be especially difficult if this fire was positioned further from the river.

## WFDSS: Fire Spread Probability model (FSPro)

- Inputs:

- Canopy characteristics from spatial layers
- Foliar moisture defaults to 100%
- Tree species and dbh hardwired to GF/20cm
- User sets “spotting probability”
- Weather probabilistic or forecast or combination, but static for each burn period
- 20-foot wind speed/direction probabilities from RAWS data.

- Output: fire growth probability map

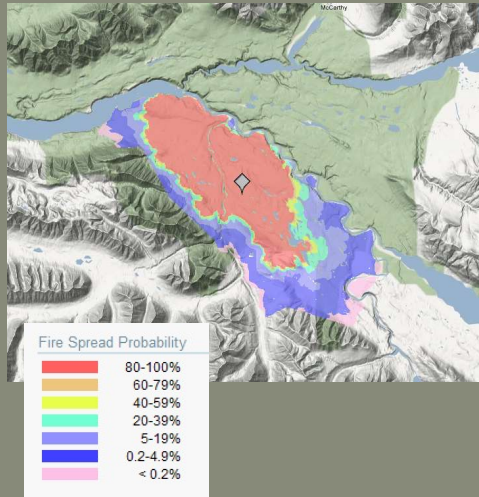
Next, we looked at FSPro.

FSPro inputs are listed on the slide.

For all MTT methods, spotting tree species and dbh is hard-wired to Grand Fir at 20cm.

FSPro output is a probability map....that typically looks like this (next slide):

## WFDSS: Fire Spread Probability model (FSPro)



- Typical 14-day output
- Inputs include forecast and climatological wx
- Output is a probability surface map
- Cannot distinguish spotting without inclusions
- No spotting across river occurs

This is typical FSPro output, after model is calibrated to represent fire growth for this particular fire.

Inputs include a 3-day forecast and climatological weather (May Creek RAWS) for the 4<sup>th</sup>-14<sup>th</sup> days, used to create ensemble weather scenarios for 2000 iterations/fire scenarios. This output shows zero probability that “2000 different fires” will spot across either river in the next 14 days.

This output uses a RAWS that is presumed to represent wind direction accurately, but those winds are not the winds of concern. Predominant wind direction from this station is West. South winds were the winds of concern.

That said, can FSPro be used to understand wind speed thresholds for spotting?

B+ gives us windspeed thresholds and max ember distances, but no geographic display and no link to torching fire behavior.

STFB shows us where ember production occurs, but uses random spotting distances for each run.

FSPro also does not show us fire behavior or thresholds, but it runs the random spotting function hundreds or thousands of times for a probability.

In this case, it was clear that any probability of fire showing up on the north side of the river would indeed indicate spotting.

Spotting would not be so easy to ascertain without such a substantial barrier.

(20090725\_1000\_14days\_forecastNWS)

## WFDSS: Fire Spread Probability model (FSPro)

### • Spotting process uses MTT

- Nodes on a fixed grid are randomly selected to loft a single ember based on user-set “spotting percent”.
- A random ember distance is selected based on negative exponential distribution (0-max distance); very few embers travel max distance.
- Fuel moistures (POI) are not considered as in our B+ matrix approach.
- Remains stochastic due to random node selections and ember distances.

FSPro uses MTT for spotting, as described earlier for STFB.

Important points are that:

- Nodes on a “fixed grid” are randomly selected to loft a single ember based on “spotting percent”,
- A random ember distance is chosen, very few embers are lofted the max distance, and there is no way to know if the max distance was randomly chosen,
- The user-defined spotting probability is a simple scaling factor that determines how many of the live embers grow into spot fires, but has little to do with actual fire behavior.
- Fuel moistures or Probability of Ignition are not considered, as in all the tools.
- Ember production is stochastic due to random node selection and random ember distances.

## WFDSS: Fire Spread Probability model (FSPro)

### • Modified Inputs to Assess Spotting Potential:

- Spotting potential=20% as calibrated, and 100% to see full range of potential results.
- Winds hardwired at specific speed and direction regardless of climatology or forecast.
- Run time was 1 day with 256 fires rather than several days with thousands of fires.

### • Chakina Fire results for spot fire thresholds....

We modified the traditional FSPro inputs to see what we could learn about how it modeled spot fires.

We ran 20%....calibrated

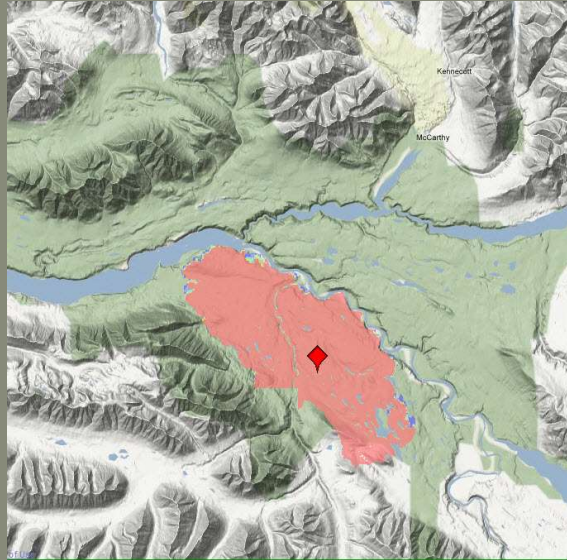
But we also set spotting potential to 100%....so that every pixel that *\*can\** loft an ember *\*will\** loft an ember.

Again, spotting at 100% does not mean that embers will be thrown the maximum distance.

We “hardwired” winds at *specific speed* and direction of interest to understand the threshold under which spotting might occur.... rather than depending on climatology of a non-representative station in order.

Run time was one day.....this worked with the current fire perimeter because the fire was already within one burn period of the barrier.

S 10mph 1 day, 20%

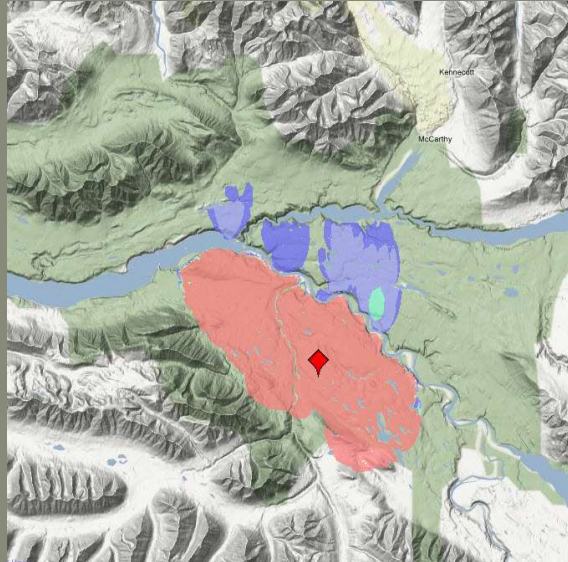


Let's review our FSPro results

We ran FSPro with a 10 mph south wind at 20% spotting probability because that's what we had used to calibrate the model to recent fire growth.

The fire does not cross the barrier.

S 15mph 1 day, 20%



At 15 mph, the fire does cross the barrier, and in the area of highest concern/risk.

Out of 256 attempts, the fire spots to our area of concern 49 times (19%).

S 10mph 1 day, 100%

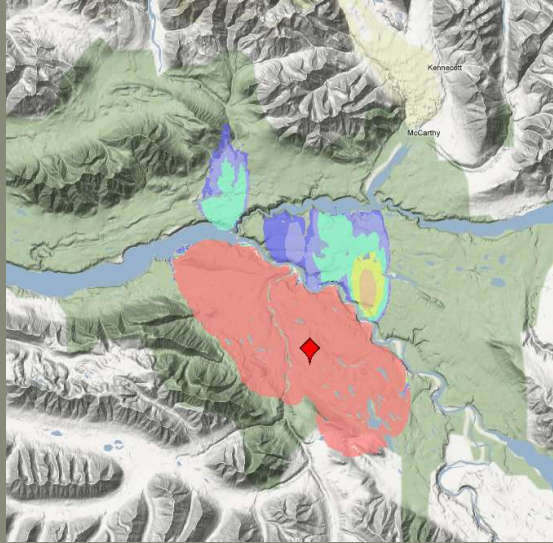


But, running FSPro with 20% spotting probability means that 80% of the lofted embers were randomly selected to NOT ignite spot fires. Since we were looking for thresholds and potential for spotting, we wanted to know where ALL the embers were landing.

So, we ran FSPro with 100% probability of spot fire ignition, which is not something you would do in a standard FSPro run.

Again, the fire does not cross the Chitina River with a 10 mph wind....

S 15mph 1 day, 100%



And, again, the fire crosses the barrier with a 15 mph wind.

It crosses at the area of highest concern.

Surprisingly, this output is not very different from the run that used 20% spotting—we have the same relative amounts of spotting.

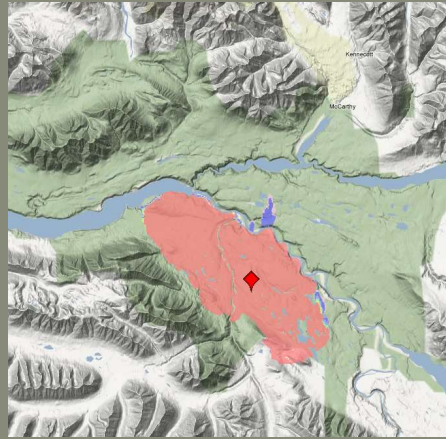
With 100% spotting, you would NOT want to show the image as a representation of fire growth.

S 12 mph 1 day, 100%

256 SIMULATED FIRES



2528 SIMULATED FIRES



Although we didn't show all the slides, 12mph was the FSPro-identified wind threshold where spotting first occurred.

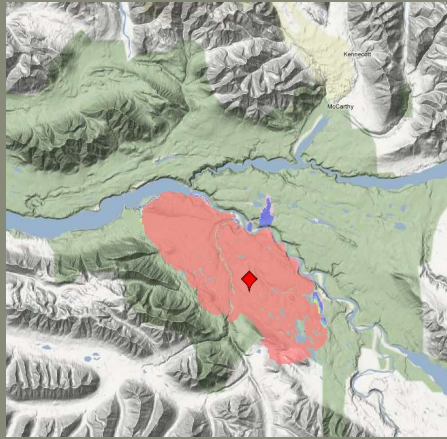
We wondered if it mattered that we only ran 256 simulations with this stochastic spotting process.

What if we ran 2500 fires instead of just 256? The result is essentially the same, but shows a small amount of variation.

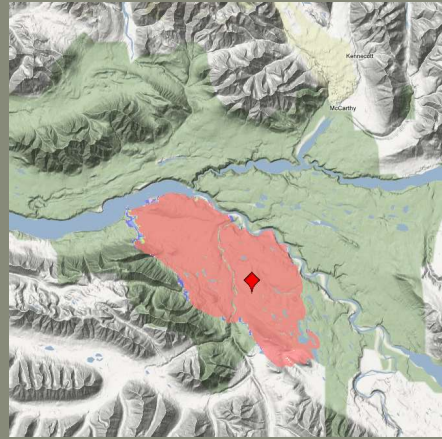
It does not change our interpretation of the threshold.

12 mph, 1 day, 100%, 2528 fires

SOUTH WIND



SOUTHEAST WIND



We also modeled different wind directions—which is easy to do in FSPro by copying a run and changing only the wind azimuth.

With a SE wind, the fire does not spot across either the Nizina or the Chitina Rivers.

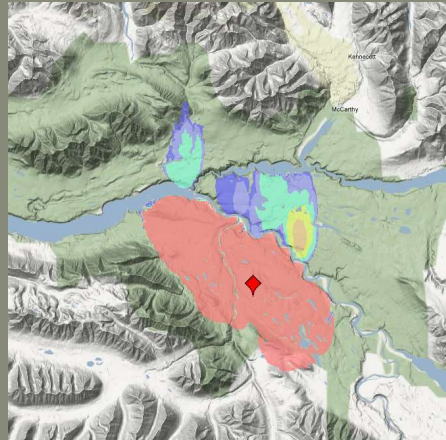
## Answering the Question with FSPPro

With a South Wind 10-15 mph, likelihood of spotting increases at certain locations indicated on the map—we see high and low probability areas.

Do not know max spot distance.

Do not know where torching occurred.

This map does not accurately indicate fire growth—parameters were set only to assess spotting across barrier.

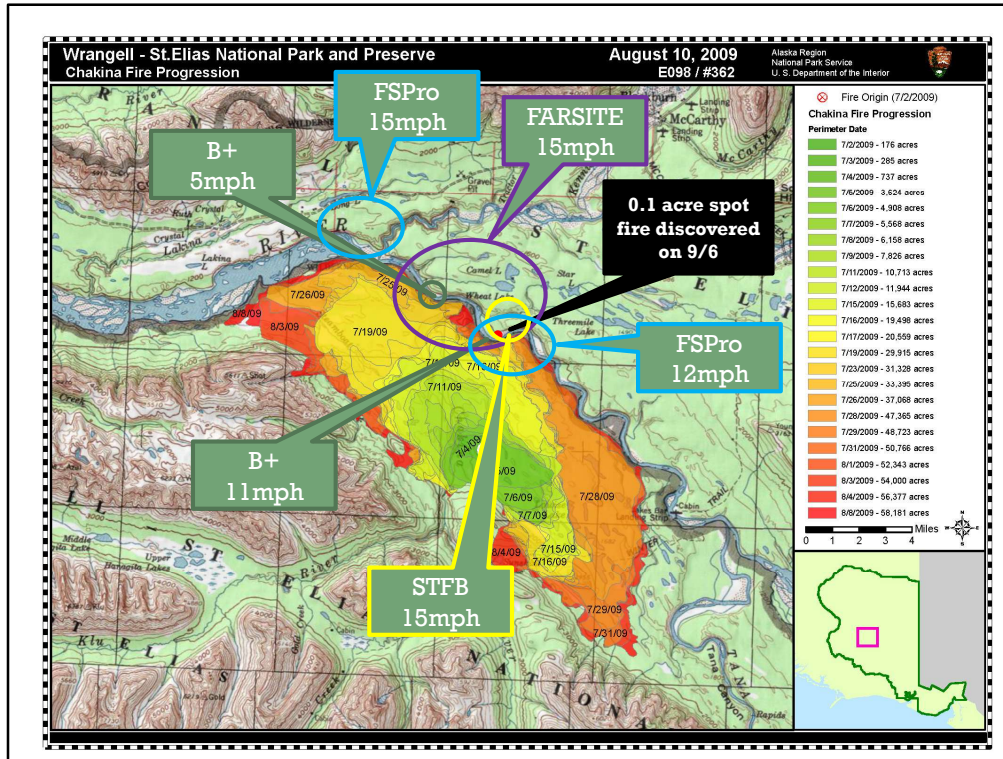


When answering the question with FSPPro, we could say that a South wind of 12 mph increased spotting at certain locations—and there was variability among those locations.

We do not know the maximum spot distance

We do not know where torching was most likely

This output does not indicate fire growth probabilities because it was run at 100% spotting, which does not represent fire growth.



This is a final progression map. Keep in mind that burnout operations did occur along the river that may have influenced where spotting occurred. However, a spot fire was discovered at the location indicated by the black arrow.

The results from the models are shown:

Behave Plus indicated 5 mph at a narrow point, and 11 mph in a steeper cliffed out area.

Short Term FB results are shown in yellow—15 mph in the area of the actual spot fire.

FARSITE is shown in purple—15 mph in a larger area along the river.

And FSPPro is shown in Blue with 12 mph as the threshold where spotting first occurred near the actual spot fire location, and 15mph to spot across to the major area of concern.

## Conclusions

- Only BehavePlus calculates the Maximum Spotting distance, but is not geospatial.
- STFB can quickly and spatially calculate fire behavior that produces embers, and can show spot fires, but may not give Max Distance.
- NTFB/FARSITE can accurately represent fire growth and behavior, but fires must be “grown” to the area of concern at the right time.
- FSPro shows probability of spread and spotting, but does not show fire behavior or Max Distance.
- Spot fire modeling is built on many, many assumptions.

In Conclusion,

As the only model where the user can be assured of obtaining the maximum spotting distance for a given set of inputs, BehavePlus can be used to obtain the minimum wind speed required to produce spotting across a barrier, but only at a few locations across the fire area. Because it always uses the maximum spotting distance, BehavePlus appears to indicate that lower wind speeds are required to produce spotting across the barrier than is indicated using the geospatial models.

STFB is useful for quickly showing where passive and active crown fire occur (and embers can be produced) across the entire landscape. STFB can also be used to roughly determine windspeed and direction thresholds required for spotting across a barrier. However, due to the stochastic nature of spotting every run will be different and maximum spotting distances will rarely be used.

FARSITE/NTFB is not an ideal application for this type of scenario due to the diurnal variation in temperature and humidity and the need to “grow” the fire to the area of interest with the right timing.

FSPro can be used to show where spotting is likely to occur. If run with only forecasted weather, FSPro can be used as a super-STFB run, capturing all potential variability in spotting for a given scenario. However, it does not show where torching/crowning are likely to occur on the landscape.

Finally, we want to emphasize that spotting distances, whether used in non-spatial or spatial modeling tools, are built on many many assumptions.

Management questions related to spotting should be approached with caution. Albini was right, spotting is a vexing phenomenon.

# Thanks

- Our thanks to...

Pat Andrews  
Jennifer Barnes  
Stu Brittain  
Mitch Burgard  
Mark Finney  
Chuck McHugh  
Erin Noonan-Wright  
Joe Scott  
Rick Stratton

for helping us understand the modeling of  
spotting fire behavior in various tools.  
Don't forget to check out the handout!